THE EFFECTIVENESS OF COMMERCIALLY AVAILABLE WETTING AGENTS FOR COMBATING ON-SITE SOIL WATER REPELLENCY IN SANDY SOILS

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Abstract Soil water repellency (hydrophobia) is a widespread phenomenon affecting millions of hectares of mostly dry soils throughout the world. Soil hydrophobia results in uneven water distribution in the soil profile, poor plant performance and patchy growth. The most common strategy for alleviating soil water repellency in urban areas (e.g. landscape, gardens and ovals) is application of wetting agents most of which are surfactant based. Inspired by international research on surfactant based detergents, recent laboratory experiments were conducted at Murdoch University to test the efficacy of leading locally available commercial wetting agent products and their effect in sand. Results from capillary rise and double ring infiltrometer tests indicate that the presence of different wetting agents in sandy soils may enhance water infiltration at time of application but in matter of days often increase soil water repellency rather than reducing it. It is suggested that surfactant molecules in the wetting agents are adsorbed on the sand particles in a similar way to the organic hydrophobic materials that are coating them. The interaction between the surfactants and soil particles seem to be the key to a better understanding of these observations and further investigation is needed.

Keywords Wetting agents, water repellent soils, infiltration, capillary rise

INTRODUCTION

Water repellent (hydrophobic) soils are such that they do not wet spontaneously when a drop of water is placed upon their surface. Depending on the severity of water repellency, water drops will penetrate the surface after a few seconds, or for extreme water repellency, infiltration may be delayed for hours or even days (DeBano, 1981; Doerr et al., 2000). Since water infiltration into water repellent soil-profiles is partial, it makes the water unavailable for the plant roots. If some water penetrates the profile, it is characterized by preferential flow path causing the soil to wet in some places, and remain dry in other places. This phenomenon is also called localized dry spots and often results in uneven water distribution in the soil profile, reduced plant growth, patchy and uneven plant emergence, water ponding and enhanced runoff and erosion (Blackwell 1996). Soil water repellency is a widespread phenomenon affecting millions of hectares of mostly dry soils throughout the world (Ritsema and Dekker, 2003). It is generally considered to be the result of coating by a range of complex organic acids during the decomposition of organic matter. These compounds have non-polar section such as humic acids, plant waxes (e.g. fatty acids, alkanes and alcohols) fungal hyphae and others (Ritsema and Dekker, 1994; Karnok and Tucker 2004). Soils with smaller surface areas are more prone to water repellency as it takes less hydrophobic material to coat individual particles, compared to silt or clay (Karnok and Tucker, 2002, Poulter, 2006). Although water repellency has been widely studied, comparatively little is known about its precise causes and characteristics. Consequently, no optimum management strategies exist for water repellent soils (Ritsema and Dekker, 2003).

The most common strategy for alleviating on-site (e.g. golf courses, gardens) soil water repellency is to apply nonionic surfactant based wetting agents and there are a number of products available on the market in both liquid and granular form (Poulter, 2006; Halett, 2008; Oostinde et al., 2009). Nonionic Surfactants (surface active materials) are molecules having "hydrophobic tail" and "hydrophilic head" but have no net charge. Many are considered to have low phytotoxicity. They are detergent-like substances that reduce the surface tension of water, allowing it to penetrate and wet the soil more easily. These compounds allow the water to 'spread out' by weakening the cohesive forces allowing adhesion to occur. For the most part, the chemical make-up of these materials is ethylene oxide and propylene oxide units known as EO/PO block copolymers (Poulter, 2006; Kostka et al., 2007). These are essentially long chain polymers of varying complexity with a hydrophilic end and a hydrophobic end. Theoretically, when a surfactant based wetting agent is added with water to the soil, the polar portion of the wetting agent surfactant bonds with the water while the non polar portion bonds with the non polar organic coating, thus allowing the soil or sand particle to wet (Figure 1). As long as there is sufficient wetting agent bonding with the organic coating, the soil or sand particle is not expected to be water repellent (Karnok and Tucker, 2004).

It was also noted that in the absence of water repellency, a wetting agent would have little effect on the soil itself. The effectiveness of different wetting agents in improving soil wettability was demonstrated in several studies (e.g. Miyamoto, 1985, Throssell, 2005, Karnok, 2006; Kostka et al., 2007)

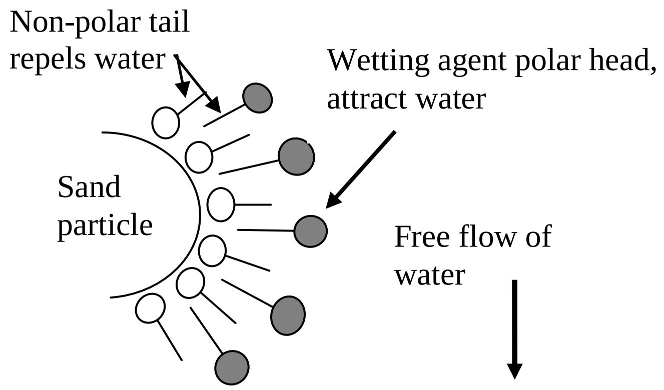

Figure 1. The theoretical mode of action of wetting agent to alleviate water repellent soils.

Other observations demonstrated that some wetting agents have not improved and even increased water repellency (Leinauer et al., 2007). In a different study it was demonstrated that coating of sand by anionic and nonionic surfactants resulted in enhanced water repellency (Wiel-Shafran et al., 2005). The authors showed that even at low concentration of 10 mg/kg of anionic and nonionic surfactants significant water repellency was observed. Similar results for higher surfactant concentrations (i.e. ~3000 mg/L) were found by Abu-Zreig et al. 2003) who demonstrated that the applications of anionic and non ionic surfactants caused decreases in the capillary rise and penetrability of water to sandy loam soil.

Although not directly tested, in contrast to Karnok and Tucker (2004), it was suggested by Wiel-Shafran et al. (2005) that the hydrophobic tail is the part facing the pores rather than the hydrophilic head, and therefore causing the sand to become water repellent. In other words, the organic surfactant molecule behaves just like natural hydrophobic molecules once absorbed on the sand, thus enhancing its hydrophobicity.

Therefore, the aim of the current study was to test the effectiveness of commercially available surfactant based wetting agents to ameliorate soil water repellency in sandy soils.

MATERIALS AND METHODS

Five commercial wetting agents designated as products A, B, C, D and E (2 granular and 3 liquid based products) were tested by studying their effect on capillary rise and infiltration of water into typical native partly hydrophobic sand that is used for gardening. About 1 m^3 sand was collected from a garden area at Murdoch University, Perth, WA. The soil was sieved using a 2.0-mm sieve and mixed. Representative subsamples were dried (105 ^{o}**C**) and characterized. The sand properties are summarized in Table 1.

Table 1. Physical and textural characteristics of sandy soil from around Perth, WA, that was used in the study.

Org C (%)	CEC* (meq/100g)	Water content (%)	Sand Fraction (%)		Sand (%)	Silt (%)	Clay (%)
			Fine (20-212µm)	Coarse (212-2000 µm)			
0.4 ± 0.02	4.6 ± 0.02	0.4 ± 0.02	49.21 ± 0.21	47.37 ± 0.13	96.6± 0.3	0.6 ± 0.02	2.2 ± 0.05

* Cation Exchange Capacity (CEC) is Na^{+} + K^{+} +Ca^{2+} +Mg^{2+} (meq/100g), top soil collected at 0-15 cm depth, sub soil collected at 15-25 cm depth, n=3

Capillary rise experiments

The effect of wetting agents on capillary rise was determined on the sieved dry subsample by laboratory experiments according to procedure suggested by Wiel-Shafran et al. (2006) and outlined below. The bottom of the soil columns (*polypropylene*; dimension: internal Ø 38mm x length 295 mm) was covered with a fine mesh net. The columns were then packed with sand that was dried at 105 ^{o}**C**. Similarly, a second set of columns were packed with sand that was burnt in a muffle furnace for 4 h at 450 ^{o}**C** to remove the organic matter. The columns were attached to a stand and placed on a balance (AND, model GF-2000) as illustrated in Figure 2. An open reservoir containing water (control) or a wetting agent solution (prepared according to the manufacturer's instruction) was then raised beneath the column until the water surface touched the bottom of the column. Being a measure for water repellency, capillary rise was assessed as the weight of water rising in the column registered by the balance as a change in mass. The weight change due to the capillary rise of the tested solution in the columns was recorded with a data logger once every 5 seconds. Once the capillary rise stopped as indicated by no change in weight over time, the columns were dried in the oven at 105^{0}C. The columns were cooled to room temperature and another capillary rise experiment was repeated using scheme water as the rising solution. This procedure was considered to represent common use of a wetting agent which is then followed by irrigation practice with water without the wetting agent.

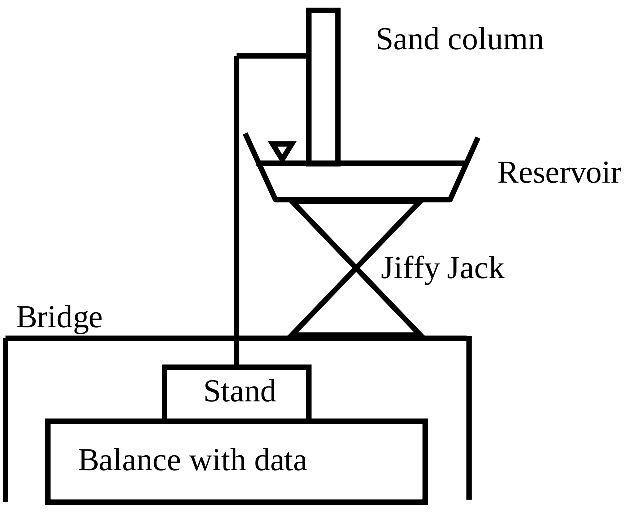

Figure 2. Illustration of the capillary rise experimental set-up

Measurement of infiltration rate using a double-ring infiltrometer

Preparation and irrigation regimes

The mixed sieved sand (50 L into each barrel) was introduced into 18 plastic barrels (65 L, inner Ø42 cm x height 47 cm). Barrels were shaken after each sand load was introduced to settle the sand. Into each of the barrels a double ring infiltrometer was installed as outlined below.

Initially, to further compact the sand, the infiltration rate of all barrels was measured by the double ring infiltrometer technique using scheme water as described below. The same volume of water was used in all barrels. The barrels were left to dry for 5 days and the infiltration rate was tested as outlined below. The wetting agent solutions were prepared according to the manufacturer's instructions on the product. Each wetting agent was applied into 3 barrels and 3 barrels were used as control into which scheme water was applied. The experiment was set in randomized block design. The barrels were left to dry for 3 more days and the infiltration rate was measured again using scheme water in all treatments. The barrels were left to dry again for 7 days and the infiltration rate was re-measured with scheme water. This procedure was conducted to mimic common irrigation practice of large pots. Differences of the percent reduction among treatments at each date were tested by analysis of variance. Prior the analysis data were arc-sinus transformed to maintain normality of the residual (Zar, 1999).

Double-ring infiltrometer experiments

The double ring infiltrometer method is commonly used to evaluate the saturated infiltration rate in soils (Lai and Ren, 2007). Two 22 cm high plastic rings were driven concentrically 10 cm deep into the soil with minimum soil disturbance. The outer and inner ring diameters used were 17 and 8.3 cm respectively. The outer ring was filled with water after which the inner cylinder was filled to a level equivalent to an initial 70-80 mm head. The time taken for the water level in the inner cylinder to drop to 20 mm was recorded using a timer. Thereafter, a measured volume of water that is equivalent to 20 mm in depth in the ring was filled successively and the time taken to infiltrate this amount was recorded. When the amount of water entering into the soil did not change much with time for 5 consecutive measurements, steady-state flow was assumed and the average infiltration rate was calculated (based on these last 5 measurements). Water level in the outer ring was maintained at a level about the same as the water level in the inner ring.

RESULTS AND DISCUSSION

In this research, we indented to study the changes in sand hydraulic properties followed by simulation of quantitative on-site use of a number of commercial wetting agents. Capillary rise and infiltration test were used as indication of changes in the sand water repellency. As expected, the capillary rise of the burnt sand was significantly higher than in the native sand, demonstrating the contribution of organic matter to the sand hydrophobicity (Figure 3). Initially, there was virtually no difference in the capillary rise between water and the wetting agent solutions for the native soil (Figure 3a) and slight reduction in capillary rise in all wetting agent solutions as compared with water in the burnet sand (Figure 3c). The reduced capillary rise of the wetting agent solutions resulted from their lower surface tension. This phenomenon was not observed in the native soils, most likely because it was masked by the natural hydrophbicity of the sand. Repeated capillary rise of the wetting agent-coated sand resulted in a distinct reduction in water in both sands (Figures 3b, d). Similar findings were previously described by Weil-Shafran et al. (2005) who demonstrated that the capillary rise in organic matter free sand that was pre-coated with non ionic surfactants (i.e. type used in wetting agents) at a rate of 20 mg/kg was lower by about 50% than the uncoated sand.

An infiltration test was commenced to further test the effect of surfactant based wetting agents on water infiltration in sand. A summary of the comparative studies of the initial and saturated infiltration rates of water and five wetting agents through the Murdoch sand are shown in Table 2. Interestingly, when the saturated infiltration rate was re-measured 3 d after using scheme water as the irrigation medium, it was noticed that the average infiltration rate of the control where no wetting agents were used was 14% lower than when initially measured. Moreover, at the time of application, the saturated infiltration of water was similar or faster infiltration in all treatments as compared with the infiltration of water. Although, not statistically significant, wetting agent A was the only one that seemed to slightly enhance the saturated water infiltration through the sand over time where the rest of the treatments (except Product B) slightly reduced the infiltration. Wetting agent B significantly reduced water infiltration over time.

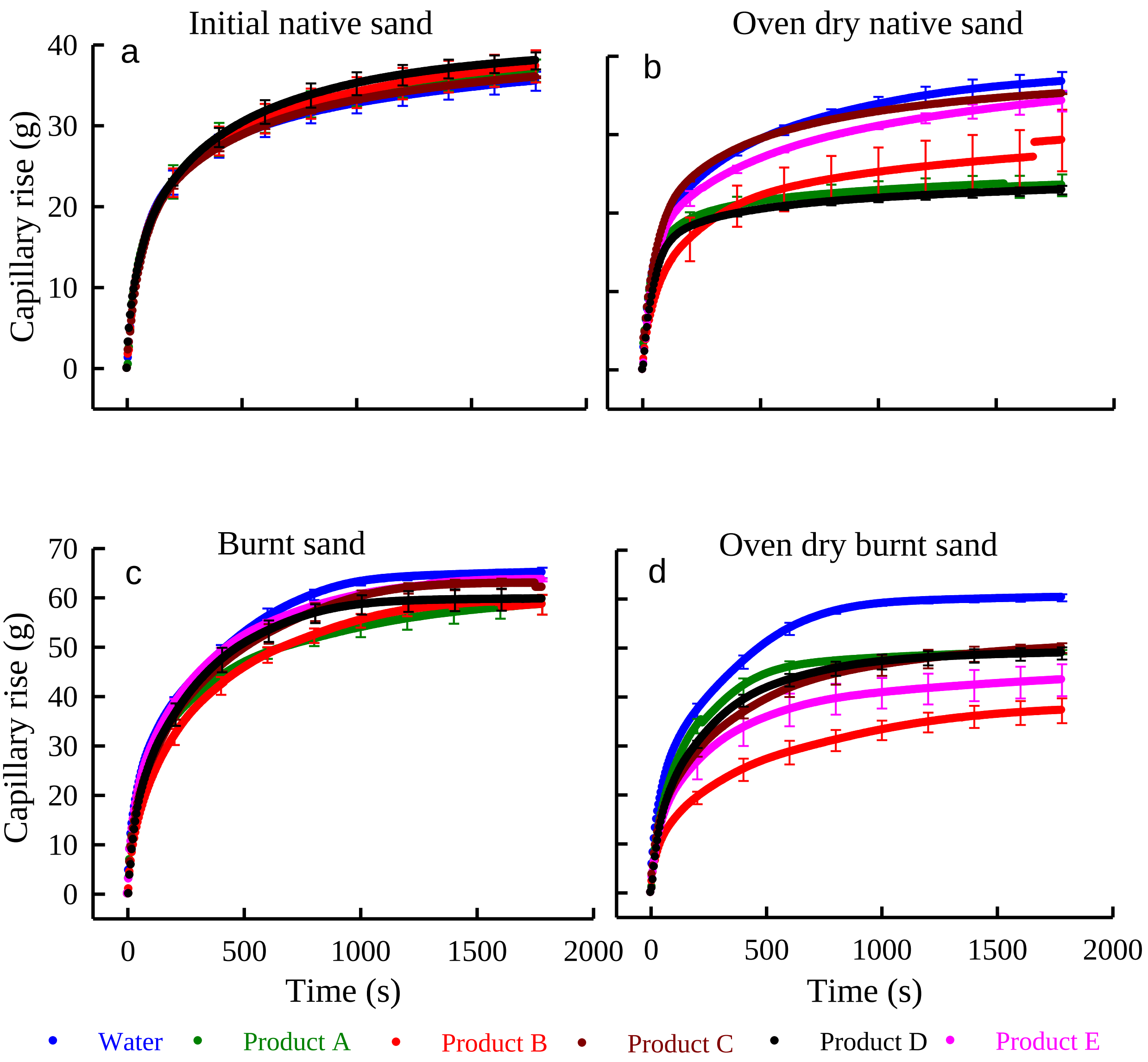

Figure 3. Illustration of the effect of commercial wetting agent on capillary rise in sandy soil. a) Capillary rise of wetting agent solutions in dry (105 ^{o}C) native sand packed in columns, b) Capillary rise of water in the sand (from a) after it was re-dried in the columns, c) Capillary rise of wetting agent solutions in sand that was packed in columns. Dry (105 ^{o}C) native sand that was further burnt at 450 ^{o}C to remove organic matter was used, d) Capillary rise of water in the sand

(from c) after it was re-dried in the columns. Products A to.E represent five commercial surfactant based wetting agents (3 liquid and 2 granular).

The initial infiltration rate in all treatments was also measured as it may more resemble irrigation of a pot. Similar to the saturated infiltration rate, the same phenomenona were observed. It should be noted that recording the initial infiltration rate is problematic as the soil moisture which affects soil infiltration was not measured and was likely to vary between individual barrels. However, it was considered as another evidence for our observations.

Table 2. Average initial and saturated infiltration rate (±SE) of five wetting agent solutions and scheme water into partly water repellent sand and the percent change in infiltration over time as measured by the double ring infiltration method. Scheme water was used for all infiltration tests after the initial application of wetting agents (i.e. days 3, 10). Results are based on 3 replicates. Letters a,b,c, indicate statistical differences ($p<0.05$) between treatments on a certain day.

Product	Initial Infiltration rate (m/d) with Wetting agents	Change in initial infiltration rate from its onset rate (%) Days after application		Saturated Infiltration rate (m/d) with Wetting agents	Change in saturated infiltration from its onset rate (%) Days after application	
	Onset	3	10	Onset	3	10
Scheme water (control)	31.4 (1.8)	-16 (12)a	-30 (14)a	17.9 (1.4)	-14 (10)a	-28 (10)a
A	29.4 (2.8)	+47 (10)b	+2 (9)b	17.3 (0.5)	-4 (6)a	-16 (4)a
B	25.1 (5.6)	-90 (6)c	-94 (2)c	18.6 (4.4)	-84 (9)b	-88 (10)b
C	48 (4.8)	-18 (3)a	-35 (15)a	25.6 (1.2)	-30 (9)a	-34 (9)a
D	46.5 (4.8)	-12 (30)a	-39 (10)a	19.8 (1.6)	-22 (20)a	-32 (10)a
E	41.9 (7.5)	-7 (16)a	-21 (10)a	24.6 (2.0)	-19 (6)a	-32 (8)a

The observations from both capillary rise and infiltration tests clearly demonstrate that the simplistic model presented in the introduction section (Poulter, 2006; Kranok and Tucker 2004) regarding the mode of action of wetting agents did not apply in the current study. It appears that in this study, for most wetting agents, the surfactant molecules behaved just like the natural hydrophobic organic molecules once absorbed on the sand, resulting in enhancement of soil hydrophobicity. The interaction between the surfactants and soil particles seem to be the key to a better understanding of these observations. More so, it is likely that there is no one mechanism by which surfactant is absorbed on soil particles making it impossible based on our current understanding to predict whether the implementation of wetting agent is going to enhance or reduce water repellency.

CONCLUSIONS

Overall, it was observed that the initial application of the wetting agents usually improved the wetability of the sand. This was likely to result from the reduction in the irrigation solution surface tension. Yet, the improved wetabillity was short lived and for most cases the water infiltration rates into the sand decreased within a few days from application. We postulated that surfactant molecules in the wetting agents were adsorbed on the sand particles in a similar way to the organic hydrophobic materials that are coating them.

These findings question the efficiency of surfactant-based wetting agents to treat water repellent sandy soils. Based on the current findings, not only that many products do not enhance long term wetabillity, some seem to enhance soil hydrophobicity. Further investigation on the interaction and adsorption between non ionic surfactants and soil particles is needed.

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